Scenario reduction for uncertainty quantification in Uranium in situ recovery

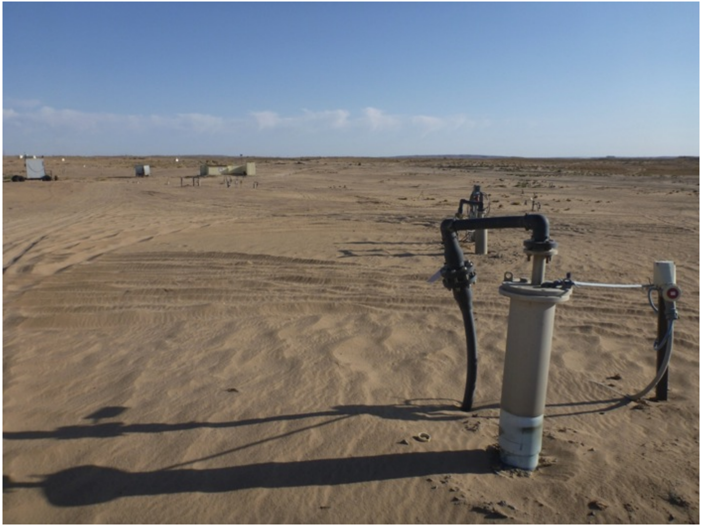
Thomas Romary, Jean Langanay, Vincent Lagneau, Xavier Freulon, Valérie Langlais, Gwenaële Petit

Geostatistics team, Centre for Geosciences and Geoengineering, Mines Paris, PSL University

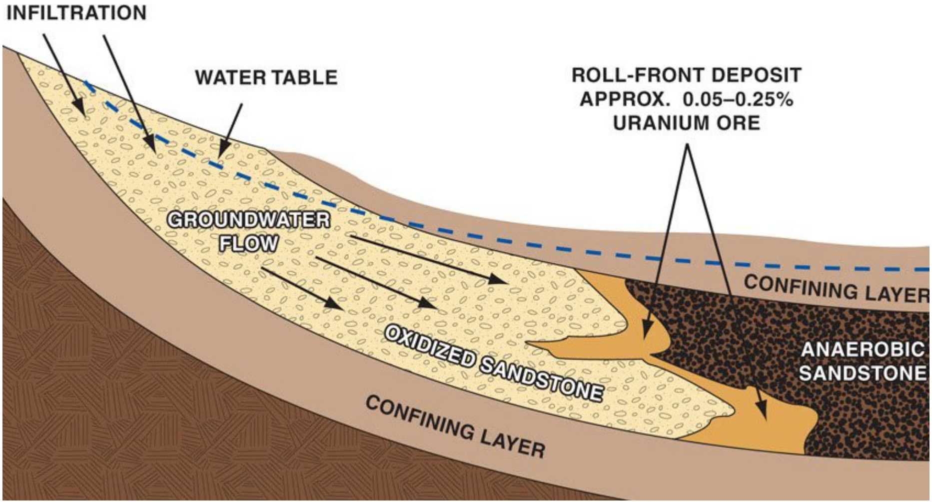
Statistical methods for safety and decommissioning

Conventional open pit mining

Uranium in situ recovery

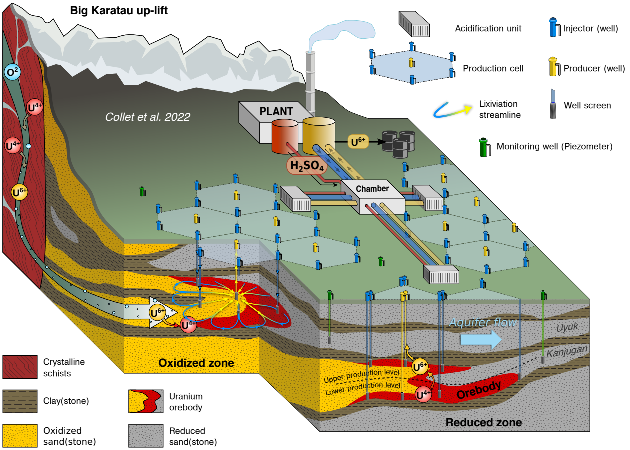


Roll front deposit



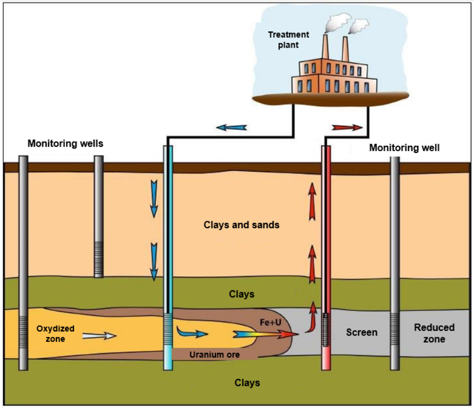
Uranium in situ recovery (ISR)

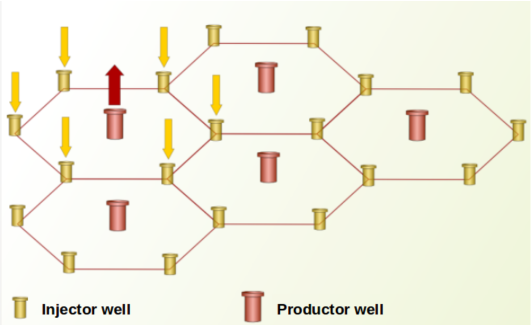
57% U world production [OECD-NEA & IAEA, 2020]



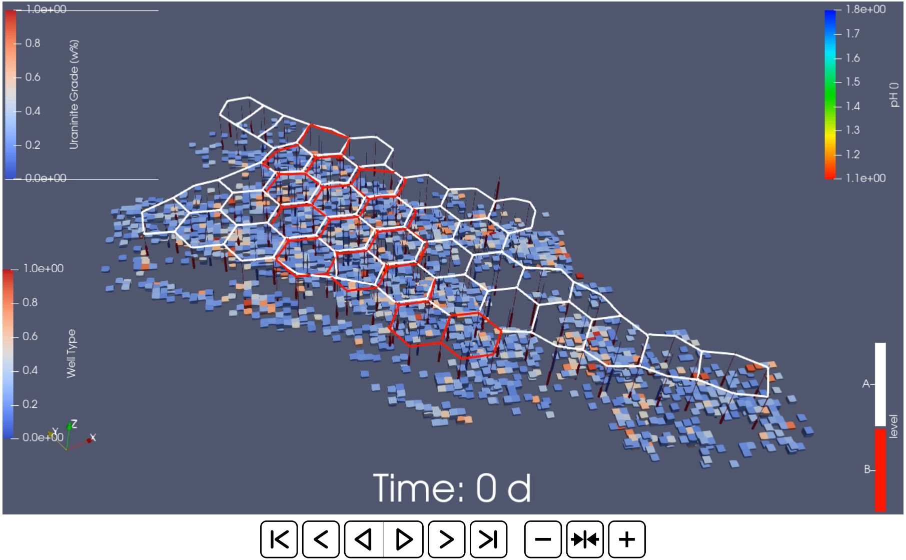
Schematic view of the Katco Uranium In situ recovery (ISR) mine and the ISR process [Collet et al., 2022]

Uranium in situ recovery (ISR)





Modelling U ISR (HYTEC)



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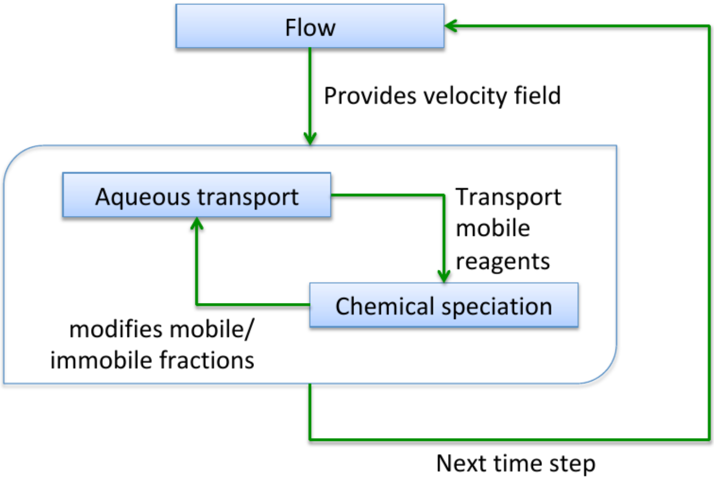


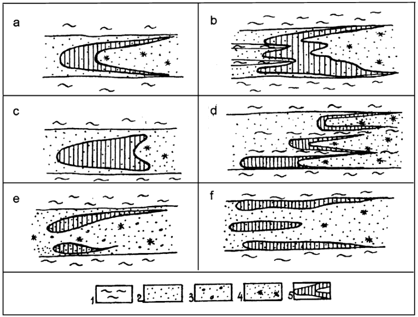
Objectives

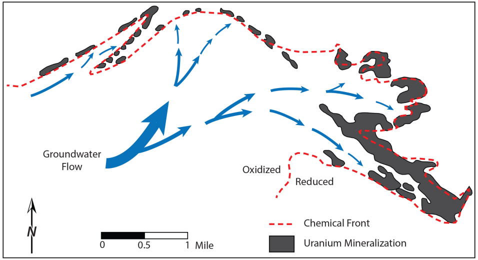
- Propagate the geological uncertainty to the production prediction at the block scale
- Evaluate the impact on mine planning

Geology of the deposit

U mineralization depends on spatially variable factors

- geological
- geochemical
- hydrogeological

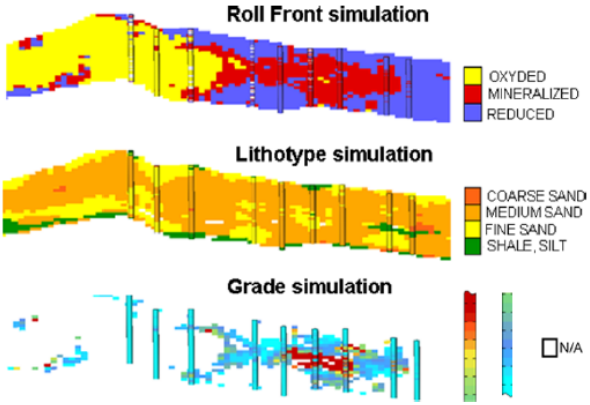




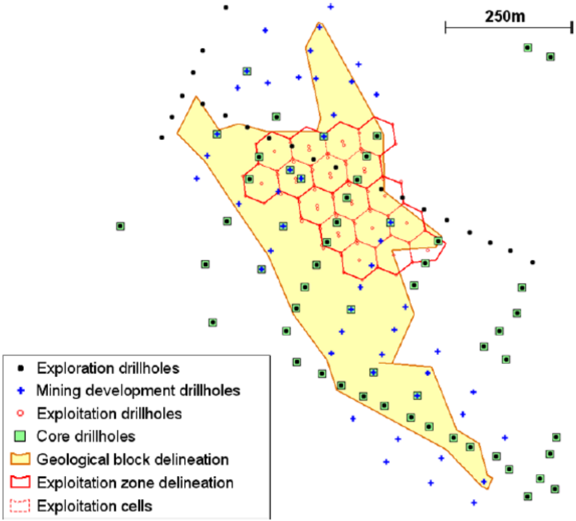
- significant diversity of mineralized U geometry
- more or less elongated and continuous bodies
- lenticular or roll shapes

Block model adjustment

1. Roll front
2. Lithotype
3. Grade



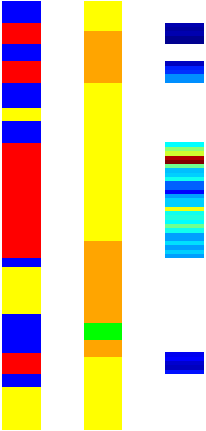
Available data



Available data

Borehole data

- Roll front facies : oxydized - mineralized - reduced
- lithotype : sand (coarse to fine) or shale
- U grade



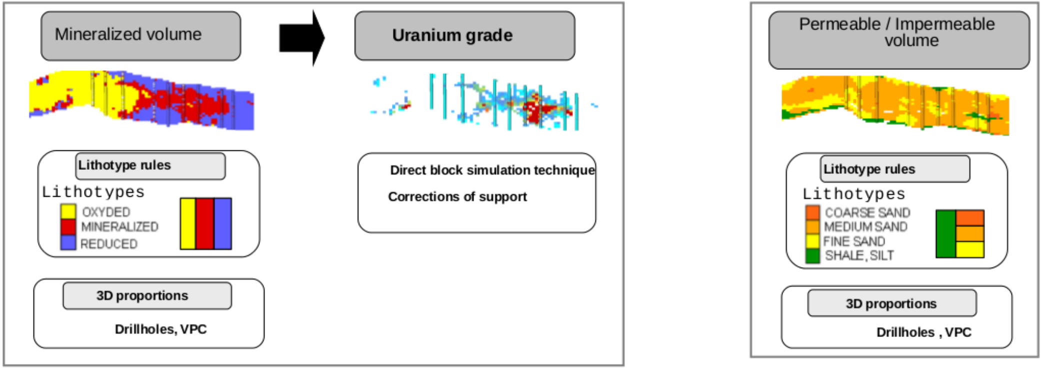
Geostatistical modelling

Petit et al. [2012]

1. Facies
   - Vertical proportions curves
   - Truncated (thresholded) Gaussian $\rightarrow$ variogram
2. Lithotype
   - Vertical proportions curves
   - Contact rules
   - Plurigaussian models $\rightarrow$ variograms of the latent Gaussian fields
3. U grade (within the mineralized facies)
   - Anamorphosis (Gaussian transform)
   - Variogram

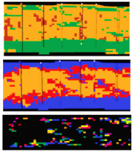
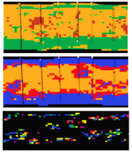
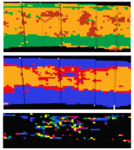
Geostatistical modelling

Petit et al. [2012]



Uncertainty Propagation

We generate a large set of realisations of the block model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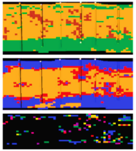
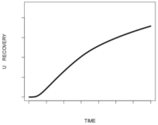
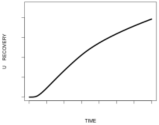
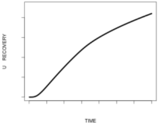


We run HYTEC







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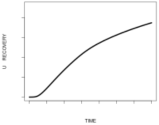
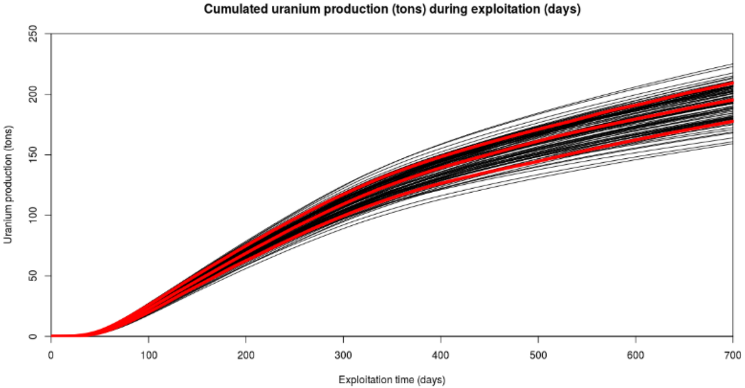


Uncertainty Propagation

Quantification of the production uncertainty



Cumulative U production curves. In red : P10, P50, P90

Intractable in practice ⇒ Scenario reduction

Uncertainty Propagation

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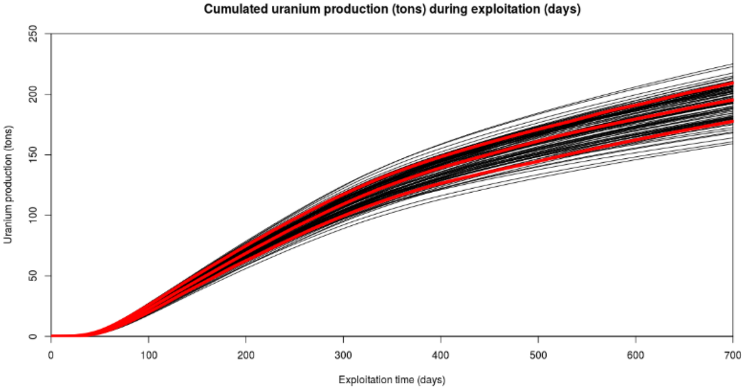


Cumulative U production curves. In red : P10, P50, P90

Intractable in practice ⇒ Scenario reduction

Scenario reduction

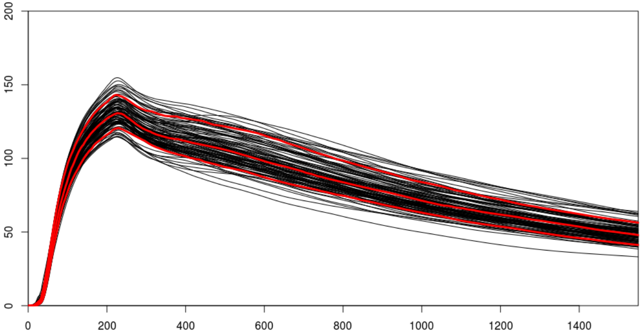
Scheidt and Caers [2009]

Ideas

- only a handful of production curves is sufficient to compute (approximately) the desired quantities
- we can discriminate between the realisations in terms of their dynamic behaviour by comparing some relevant features

Features computation

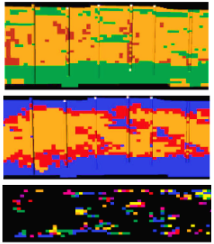
We build the features so that the distance between the realisations in the feature space is close to the distance between their production curves



Instantaneous U production curves. In red : P10, P50, P90

Features computation

Langanay et al. [2021]

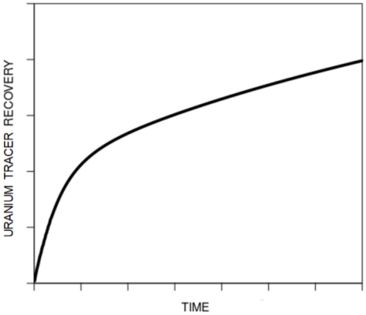


Static features

- Mineralization volume
- U average grade
- U mass
- ...

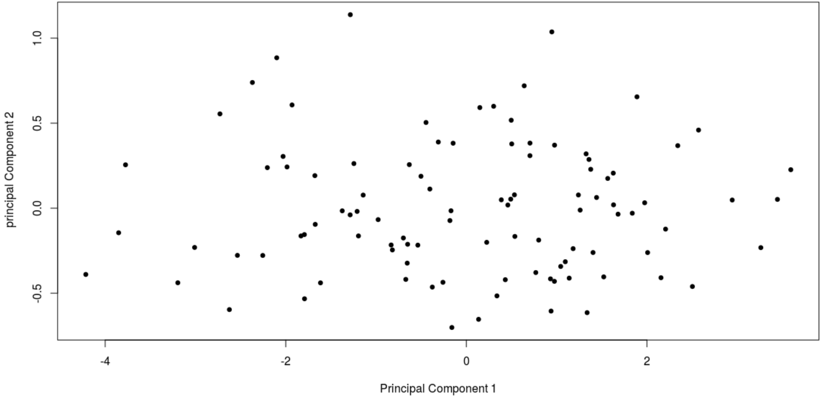
Dynamic features

- U tracer
- cinetic tracer
- ...



Feature space representation

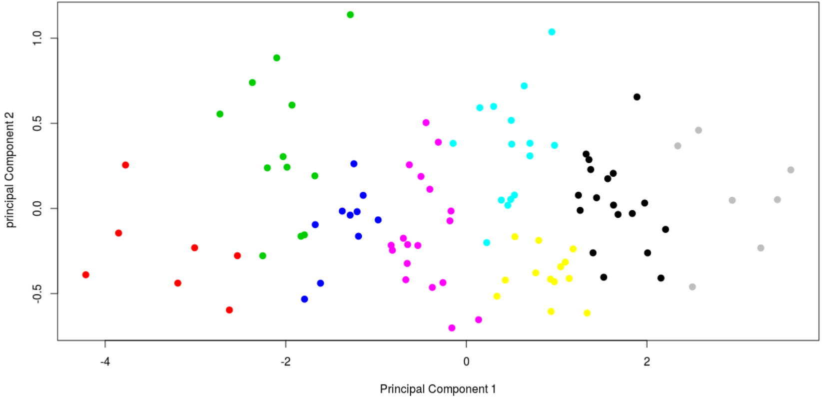
Langanay et al. [2021]



Representation of the realisations in the feature space

Clustering in feature space

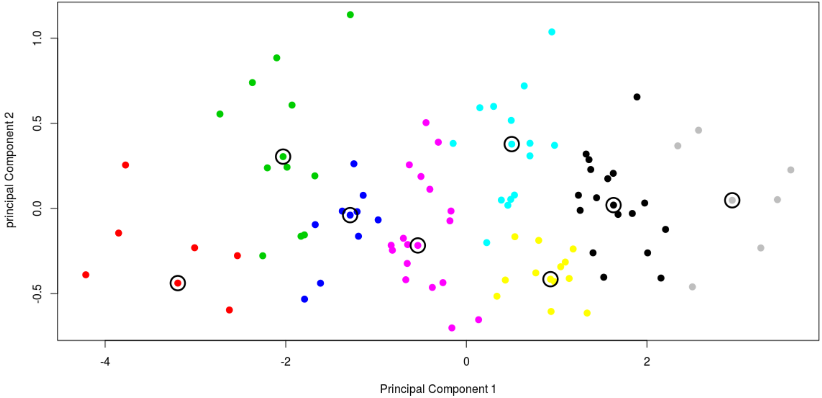
Langanay et al. [2021]



Results of the clustering

Clustering in feature space

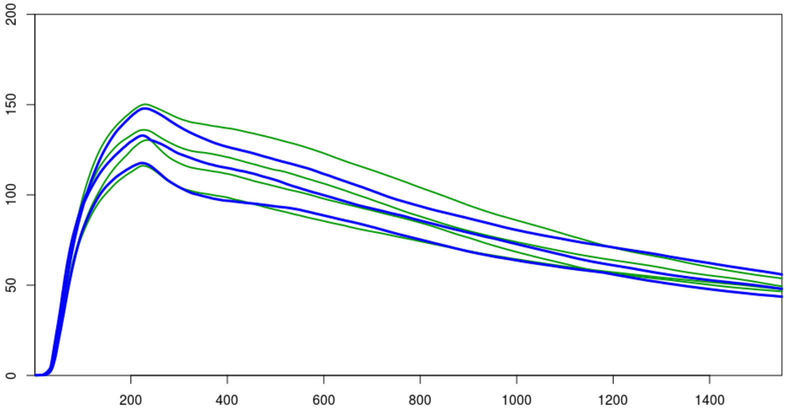
Langanay et al. [2021]



Centroids

Results

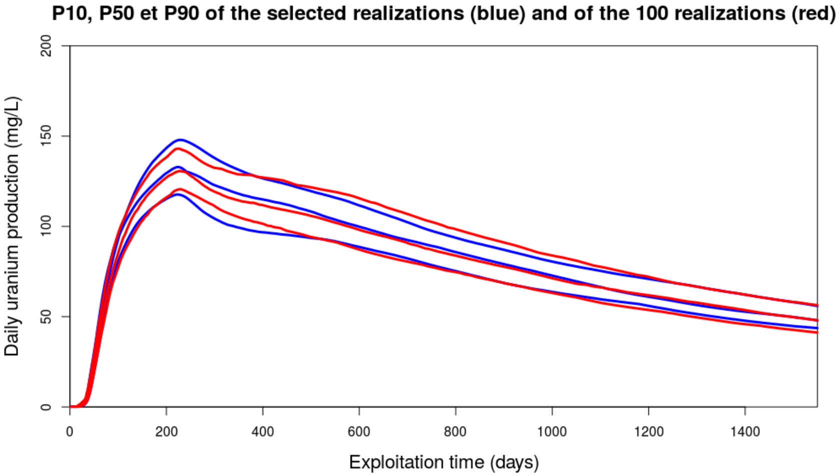
Langanay et al. [2021]



Instantaneous U production curves of eight selected realisations. In blue: P10, P50, P90

Results

Langanay et al. [2021]



More details

Langanay et al. [2021]

The method has been set up on block PB01, then validated on block PB02

Two sets of features have been considered: static (fast) and dynamic (slower)

	PB01 tonnage	PB02 tonnage
static features	3.88 t	5.81 t
dynamic features	2.33 t	2.72 t

RMSE over the P10, P50, P90

What is the impact on mine planning?

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What is the impact on mine planning?

Mine planning

Mine planning: temporal sequence of blocks start-up

- mine operation management
- computation of costs and investments

Constrained optimization of the planning

- annual production objective
- hydraulic constraints
- drilling constraints
- acid availability

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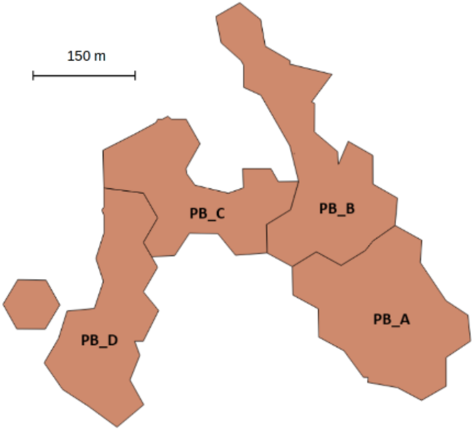
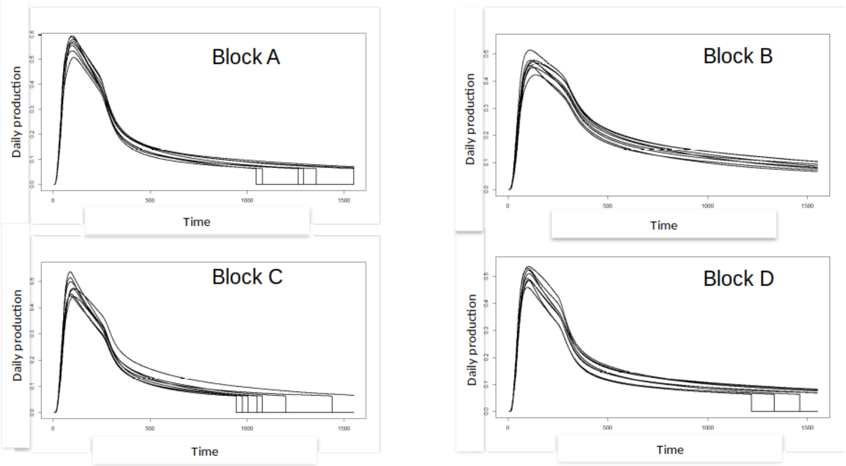


- Annual production objective: 130 t
- Block closing concentration: 20mg/L
- Minimum waiting time between two start-ups: 90 days
- Start up sequence:
  A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ D

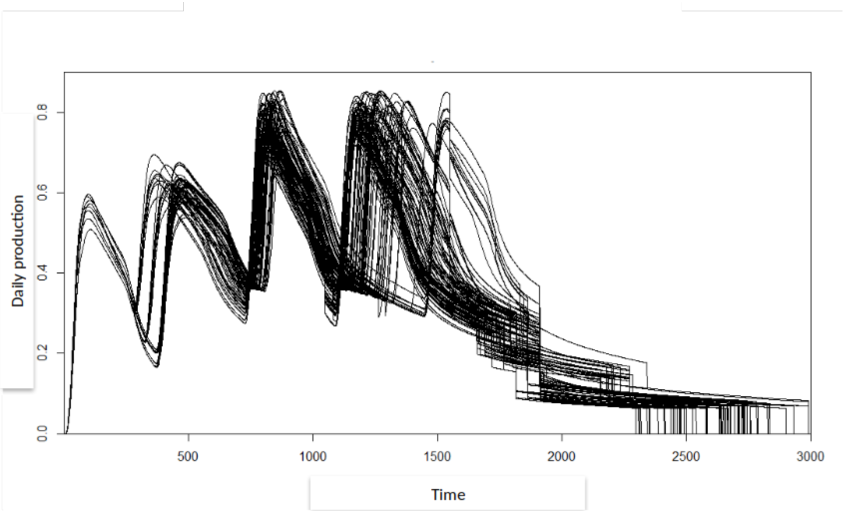
Mine planning

8 selected realisations per block obtained by scenario reduction



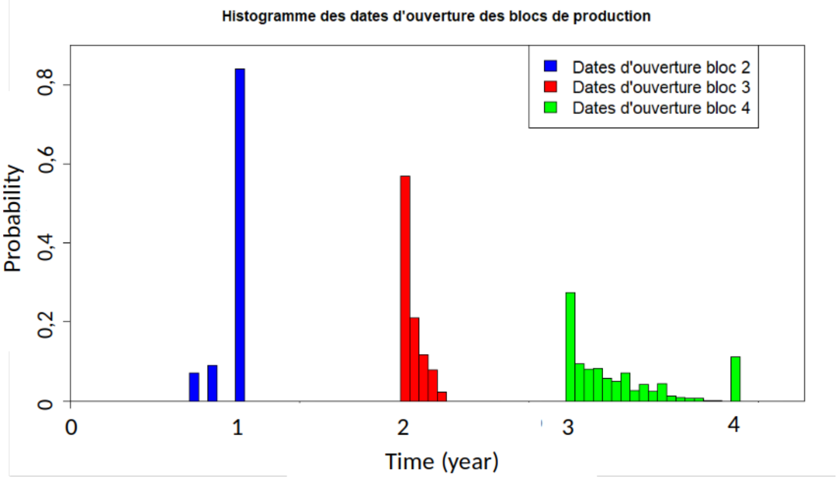
Mine planning

free start-up date



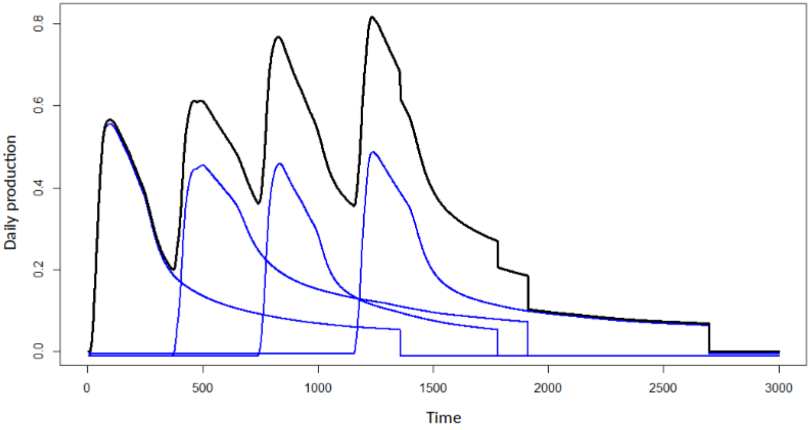
Mine planning

Histogram of the start-up dates



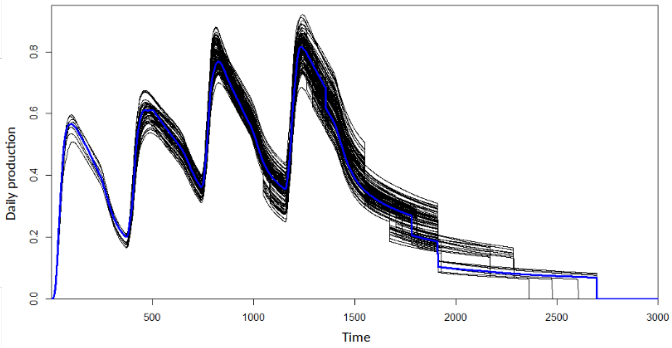
Mine planning

Setting a reference time sequence of start-up dates from the P50s



Mine planning

Variability of the production around the median scenario



year	1	2	3	4	5	6
P	0.84	1	1	1	0.28	0

Probability of reaching the production objective

Conclusion

- Propagation of the geological uncertainty to the U production thanks to scenario reduction
- Several sets of features proposed to achieve different balances between speed of computation and accuracy
- Highlighting of the consequences on mine planning

Perspectives

- Integration of other uncertainty sources (e.g. geochemical parameters)
- Management of the dependencies between adjacent blocks
- Industrial implementation
- History matching $\rightarrow$ toward a numerical twin?

References

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